Project 15 (WP4): Climate change impacts on riverine nutrient transfer and delivery to coastal sea

Project lead: Vincent Thieu
Post-doctoral researcher: Mélanie Raimonet
Project Start/End: October 2015 – March 2017

Position offer: The laboratory of excellence L-IPSL of the Institut Pierre-Simon Laplace offers a 18-months post-doctoral position to work on the impact of climate change on river-coastal area continuum.

Context: Ecological functioning of aquatic ecosystems is directly impacted by increasing human activities and climate changes. Altering these functions sometimes results in environmental damages affecting the whole aquatic continuum from headwaters to coastal sea (such as eutrophication, green tides, anoxia, fish mortality …). While regional prospective analyses are still greatly supported by statistical approaches, the newly developed biogeochemical model pyNuts-Riverstrahler, rises up the challenge of a mechanistic representation of microscopic processes operating in the aquatic continuum, scalable and compatible with regional (and up to continental) domains. PyNuts-Riverstrahler modeling framework (which include the biogeochemical RIVE model) is now operational for all the north-east Atlantic rivers (more than 350 000 km of drainage network) for assessing present nutrient transfer, including the two past decades.

The proposed research aims at further developing the model to be used in climate change impact studies. Two regional domains will be studied, namely: the Seine-Normandy river basins flowing into the Bay of Seine, and the Adour-Garonne systems associated with small Cantabrian rivers flowing into the Bay of Biscay. This work will benefit from the recent developments brought to the pyNuts modeling framework, nevertheless, it requires substantial improvements to enable the analysis of climate change impacts: (i) implementation of a hydrological module, (ii) regionalization of several biogeochemical model's parameters under changing climatic conditions, (iii) selection of relevant ecological indicators using existing estuarine model to assess the impacts of climate change on estuary and coastal area biogeochemical functioning.

Description of work: The first task is to add a hydrological module to the pyNuts-Riverstrahler modeling framework. Priority will be given to simple model structures like GR4J, as it only requires few parameters to be defined and show reasonable performances (compared to more complex and physically based models). Such an implementation also implies the use of downscaling methods to retrieve the climatic inputs (rainfall, temperature) at a finer space-scale than climate models projections (Euro-Cordex database).

In a second step the pyNuts-Riverstrahler model will be used to assess the quality of water resources forced by changing hydrologic conditions (potential changes in seasonality, prolongation of low flow periods, extreme events ...), and will incorporate the impacts of climate change on the biogeochemical functioning of river systems (response of biological processes to higher temperatures, e.g. development of bacterial, phytoplankton and zooplankton biomass, taken into account in the RIVE model). A prerequisite to the use of the pyNuts-Riverstrahler model will be the identification of parameters potentially affected by a change of climatic conditions.

Finally, the impact of climate change will be evaluated at the scale of coastal area. Riverine export fluxes from all major river systems associated with smaller coastal rivers will be analyzed. Existing estuarine model will be used to assess changes in N, P, Si, C fluxes along the salinity gradients, and to quantify deliveries to coastal area. Ecological indicator (like the existing ICEP: Indicator of coastal eutrophication potential or other indicator to be developed) will be used to point out eutrophication by nutrients and possible harmful algal blooms, hypoxia events and water acidification.

Expected skills (Young Ph-D graduate accepted):

- PhD in environmental sciences, hydrology or biogeochemistry
- Background in environment modelling (either in hydrology or in biogeochemistry)
- Computing skill, ideally Python
- Background in statistics and data processing
- Ability to work both independently and in collaboration
- Scientific writing skills for publication in scientific journals

Supervision team:

This study will strengthen the collaboration required between modeling of nutrient transfers in a context of climate change (METIS ex-Sisyphe teams), and analyzing the potential effect of these "impacted" riverine deliveries to coastal area (LSCE teams). The work will be conducted under the main supervision of Vincent Thieu from METIS and Christophe Rabouille from LSCE together with expert colleagues from the two teams, namely Ludovic Oudin (hydrology), Josette Garnier (biogeochemistry). The work will be performed in both labs METIS and LSCE according to a schedule collectively defined. Discussions by a larger L-IPSL team will be also organized.

Duration and salary:

The post-doctorate will be recruited for 18 months with a net monthly salary around 2000 euros, commensurate with experience. This includes social services and health insurance.

Contact for application:

Applications should include a vita, a statement of research interests and the names of at least two references including e-mail addresses and telephone numbers. Applications should be submitted by e-mail to Vincent Thieu, METIS (Vincent.Thieu@upmc.fr) and Christophe Rabouille, LSCE (christophe.rabouille@lsce.ipsl.fr).

Preliminary results:

Methodological developments were performed for the implementation of a semi-distributed version of the hydrological model GR4J (Perrin et al., 2003) coupled to the snow module CEMANEIGE (Valéry et al., 2014). This work was associated with a statistical analysis for the selection of adequate atmospheric reanalyzes and projections to force the hydrological model. The simulated flows by the hydrological model were used both to assess the effect of different climatic projections on hydrology and as inputs of the biogeochemical pyNuts-Riverstrahler model. Finally, the hydro-biogeochemical modelling chain was used to evaluate the climate-induced impacts of hydrological changes on nutrient concentrations and fluxes.

An exhaustive statistical analysis of the efficiency of the hydrological model GR4J-CEMANEIGE, encompassing a large range of hydro-climatic conditions and catchment area (from 10km² to 10000 km²), was first performed to select atmospheric reanalyzes. Four reanalyzes were compared: SAFRAN (France, 8-km resolution; Durand et al., 1993), MESAN (Europe, 12-km resolution; Hāggmark et al., 2000), EOBS (Europe, 25-km resolution; Haylock et al., 2008), and WFDEI (Europe, 50-km resolution; Weedon et al., 2014). The hydrological model performance was assessed by calculating the statistical criteria Kling-Gupta efficiency (KGE) between simulated and observed water flow (Gupta et al., 2009). The hydrological model showed the best and similar performances using SAFRAN and MESAN (KGE median ~0.9; Figure 1). The atmospheric reanalysis MESAN was thus selected based on its geographical extent (Europe) and its high spatial resolution (12 km), offering the best compromise in sight of generic application on western European river basins.

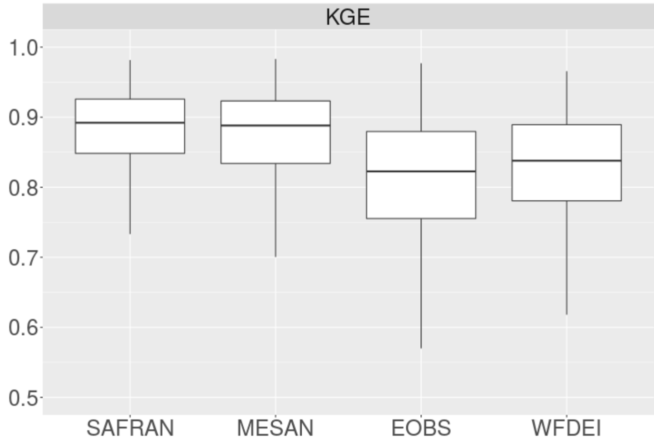

Figure 1: Distribution of statistical criteria KGE calculated between simulated and observed water flow timeseries over 1558 gauged catchments in France. The value of 1 indicates a perfect similarity between simulated and observed timeseries.

Important methodological developments were then done for a generic use of climatic data and the computation of water flow (surface and sub-surface) to fulfill requirements of biogeochemical modeling (high spatial resolution ~ 10 km², separation of surface and sub-surface water flow, ungauging catchment modelling, etc). Since the hydrological model is originally lumped, a particular effort was made to spatialize the outputs of the hydrological model. It basically implied simulations on ungauged catchment at the scale of elementary catchments and spatialization of the simulated flows within larger catchments. Results obtained with this approach on the Seine river basin using MESAN reanalyzes showed a consistent spatial distribution of mean surface and sub-surface water flows (Figure 2A) with climatic datasets (precipitation, temperature) over 1990-2010. In addition, we were able to produce a high-resolution map of the base flow index (BFI) which is the contribution of sub-surface flow to the total water flow (Figure 2B). The spatial distribution of the BFI appeared in agreement with both climatic and geological (aquifer formation, etc) settings of the Seine basin. These results tended to show the plausibility of both the hydrological model simulation and the methodology developed to spatialize at a high resolution the surface and sub-surface flows, which constitute important inputs for the biogeochemical pyNuts-Riverstrahler model.

Spatial distributions of mean water flow and BFI obtained with historical MESAN reanalysis were compared with those obtained using different BCCORDEX climatic projections (Jacob et al., 2012). Results showed consistency between atmospheric reanalyzes and BCCORDEX datasets over the 1990-2010 period, justifying the use of BCCORDEX projections for investigating the impacts of climate change.

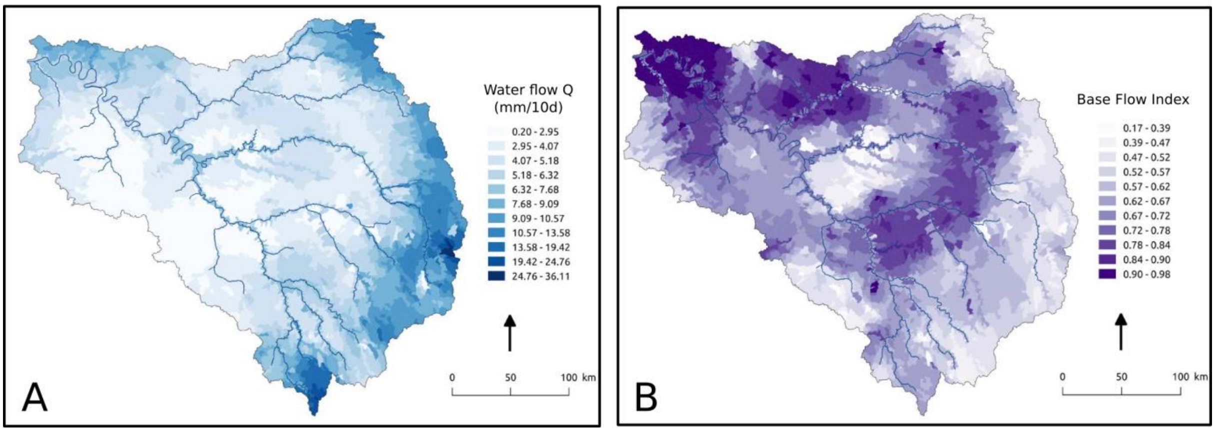

Figure 2. (A) Total water flow and (B) Base flow index as the proportion of sub-surface flow compare to total water flow in the Seine river basin.

The hydrological modelling approach forced with BCCORDEX climatic projections was then apply to evaluate the impact of climate change on water flow at river basin outlets and on the spatial repartition of water flow over river basin (example: Seine, Figure 3). A late revision of BCCORDEX projections prevented us to present the hydrological analysis for all climatic projections. However, the preliminary analysis showed a great diversity of hydrological responses to the seven tested climatic projections that are fully explained by the diversity of climatic variables (precipitation and air temperature) used as inputs of the hydrological model. Figure 3 indicates that two climatic projections led to moderate water flow increasing variations (between 0 and +10% depending on the catchments), two climatic projections led to a slight decrease (-25 to 0%), two climatic projections (red lines) clearly indicated significant water flow decreases (-20 to -50%), and one projection (dashed black line) was associated with water flow increases (0 to 50%). These results are preliminary as six of the seven projections were forced by the same General Climate Model (GCM) EC-EARTH. Inclusion of new projections forced by different GCM will allow refining the analysis to confirm water flow decreasing trends that have already been shown in the past modelling experiments on the Seine river basin (REXHYSS and EXPLORE 2070 projects). In addition, this preliminary analysis clearly showed that representing spatial heterogeneities of water flow at fine spatial scale warranties the inclusion of spatial heterogeneities and of their dynamics under changing climate (Figure 3, inserts A and B).

On-going work is performed using the biogeochemical pyNuts-Riverstrahler model in order to evaluate the climate-induced impacts of future hydrological regimes on stocks (nutrients, carbon, oxygen…) and fluxes (retention, export…) of dissolved and particulate matter. Beyond the amount of nutrient delivered to the sea (where it might support eutrophication and harmful algal bloom), we investigate spatial changes in water quality and nutrient retention along the hydrosystem, from small headwater streams to larger tributaries flowing into coastal areas, thus determining hot spots and crucial periods to appraise *indirect* CC impacts.

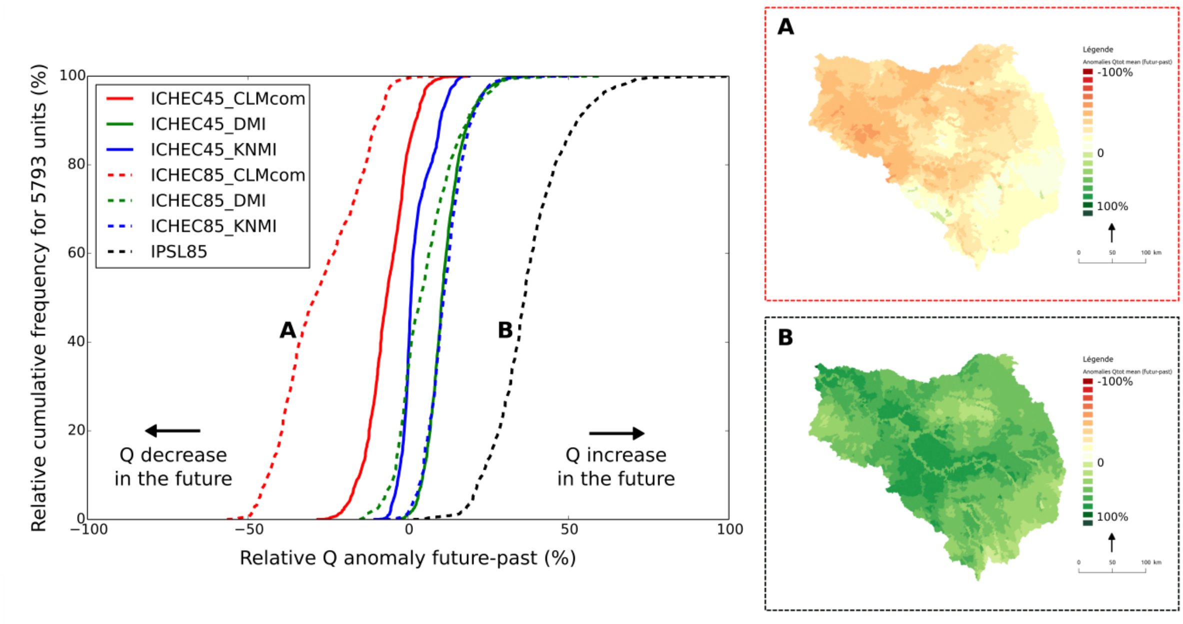

Figure 3. Cumulative frequency of relative anomalies (%) of total water flow Q for the 5793 catchment units in the Seine river basin, for 7 climatic projections (3 RCP4.5, 4 RCP8.5). Solid and dashed lines indicate RCP4.5 and RCP8.5, respectively. The spatial distribution of the relative Q anomalies, calculated as the relative ratio of Q in the future (2080-2100) compared to the past (1990-2010), is shown for two very different scenarii (A and B).

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